7/89 to 6/92.

FINAL REPORT TO:
COTTON RESEARCH AND DEVELOPMENT CORPORATION

Project Number: **DAN 47L**

Title: **HIGH YIELD PACKAGES FOR COTTON**

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Aims:

1. Determine optimum combinations of fertiliser, irrigation and growth regulator (Pix).
2. Investigate causes of, and solutions to, nutritional disorders.
3. Evaluate methods of interpreting plant tissue analyses.

Summary:

The aims listed above were achieved with about twenty field experiments over three seasons. Further sampling of 66 commercial crops was undertaken.

- Yield responses to Pix were relatively small (maximum yield responses 5%). There were consistent vegetative responses to Pix with height reductions of about 20 cm. No worthwhile maturity responses to Pix were measured. This project identified a method of evaluating crop growth to predict yield response to Pix.

- Two nutritional disorders were examined. Firstly, the long fallow (Galathera) syndrome is undoubtably due to poor infection by mycorrhiza. Zinc fertilizer strategies and possible soil management strategies were identified to minimise the problem. Secondly, waterlogging induced iron chlorosis was identified, but the condition was not completely solved by iron fertilizer: removing foliar symptoms did not necessarily improve yield.

- Nutrient diagnosis. A database has been established to indicate desirable levels of all nutrients in cotton leaf tissue. In conjunction with experiments where deficiencies are confirmed, this data can be used to assist with diagnosis of crop nutrient status.

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Background:

This project was needed because although average yields of cotton in Australia are comparable with anywhere in the world, there is still scope for improvement on at least two levels:

• On good soils, luxury inputs of fertiliser and irrigation can lead to excessive vegetative growth which can reduce yield. Under these circumstances growth regulators can be applied to prevent the rank growth. Growth regulators may increase yield or earliness of standard crops.

• Some soils have shown nutritional problems which severely limit their production. These disorders appear to be complex, involving micronutrients such as zinc. Furthermore up to 70% of all cotton is sprayed with zinc or micronutrient mixes. Many of these sprays are not necessary (nutrient not needed), or not effective (not enough of the deficient nutrient applied). Accurate recommendations need methods of assessing requirements of all nutrients.

Funds provided from other sources

NSW Agriculture paid the salaries of all permanent staff associated with this project over the three years. Office, administration, laboratory and field facilities and the majority of operating costs were also provided by the Department on Narrabri Agricultural Research Station (total contribution at least $250,000 per year). The budget from CRDC averaged $20,542 per year (8%).

Difficulties

The main field difficulty was a hail storm in the first year which destroyed some experiments. There was a staff change in the final year: Dr G A Constable left NSW Agriculture to join CSIRO. As there was no replacement in that position, there was minimal supervision of experiments in that year. Data analysis and reporting were also delayed. That problem highlights a major problem of recent years: *It is impossible for one person to adequately cover all the agronomic research necessary in the cotton industry. The industry is of a size and geographical spread that justifies many research agronomists.*

Recommendations for future research

Pix. There is no point in continuing widespread Pix research. Two areas require more attention:

- Sites with a record of excessive vegetative growth may be more responsive to multiple Pix applications than these data indicate. Further experiments are justified at those sites.

- The response of different varieties to Pix should be evaluated in more detail. Of particular interest are plant types (such as insect tolerant glabrous frego) which are taller and later maturing than normal. Experiments to examine these responses will now be done as part of the breeding program.

Nutritional disorders. Demonstration strip trials in each production area are required to investigate responses to zinc and other fertilizers. Initiatives by CRDC and the proposed CRC to provide Technical Officers in some regions should enable those demonstrations to be established. The breeding program has begun a small project to determine whether plant types can be bred to tolerate nutritional disorders.

Nutritional diagnosis. Written and computerised extension packages should be produced to allow growers and consultants to use critical plant test values derived from this research. The proposed CRC has an initiative to produce a written package (NUTRIpak) and a computerised package (nutriLOGIC) which would ensure growers had access to the information.

Application of results to industry

These results are already being applied for crop management in the field.

Publications arising from this work

Allen, S.J., Constable, G.A. and Nehl, D. (1992). Mycorrhizas, early season cotton growth and the Galathera syndrome. *The Australian Cottongrower.* 13(1), 16-18.

Brown, JF, Allen, SJ and Constable, GA (1990). Mycorrhizas and plant nutrition: long fallow disorder and cotton. *Australian Cotton Conference*, Surfers Paradise. pp 67-72.

Constable, G. A. (1989). Zinc nutrition of cotton. *The Australian Cottongrower.* 10(3), 34-35.

Constable, GA. (1990). Management of cotton with nitrogen and Pix. *Australian Cotton Conference*, Surfers Paradise. pp 155-159.

Constable, GA (1992). Managing cotton growth. *Australian Cotton Conference*, Surfers Paradise. pp 95-98. (Reprinted in *Australian Cottongrower* 13(6), 36-38.

Constable GA (1992). Narrow row cotton. *Australian Cotton Conference*, Surfers Paradise. pp 111-113.

Thomson, N.J. and Constable, G.A. (1991). Narrow row cotton: will it work here ? *The Australian Cottongrower.* 12(5), 14-18.

Weir, W. L. and Constable, G. A. (1989). Evaluation of pix strategies during 1989/90. *The Australian Cottongrower.* 10(4), 52-54.

Publication in preparation:

Constable, GA. (1993) Monitoring cotton growth to predict the need for growth regulator application. *Agron J.*

DETAILED RESULTS

A. PIX

Background

Pix (mepiquat chloride) is a growth regulator related to cycocel. The action of Pix is to inhibit the production and transport of the plant hormone auxin which itself is required for normal cell growth.

Therefore the effects of Pix applied to cotton are to reduce vegetative growth. If that reduction in growth assists fruit set, then Pix may possibly enhance early fruit set and possibly increase yield. In some areas in the USA, split applications of Pix at squaring, at flowering and ten days after flowering are more popular than the conventional single application at flowering. Label recommendations in the USA and Australia have been changed to accommodate the new strategy. In California, the split applications work best on narrow (75 cm) rows; on 100 cm rows a single application is best. In 1988 Bill Weir, a Farm Advisor with the University of California, spent six months in Australia to assist us in establishing a Pix research program. Pix reduced final plant height and resulted in more bolls set on the first 8 mainstem nodes. The yield from multiple applications of Pix was not significantly different from Pix applied in a single dose, despite showing a greater set of lower bolls. Yield differences did not always fully agree with plant mapping, or fruit count data, because Pix slightly reduced boll size.

The aim of this more extensive project was to examine Pix application strategies in Australia, particularly in relation to multiple applications, variety and crop nitrogen status.

Methods

The following experiments were undertaken

Season	Treatments
1989/90	6 Pix strategies * 2 nitrogen rates * 3 varieties
	3 Pix strategies * 2 row spacings
1990/91	6 Pix strategies * 2 nitrogen rates * 3 varieties
	3 Pix strategies * 2 row spacings
	2 Pix strategies * 2 Temik treatments * 2 Prep treatments
	2 Pix strategies * 3 Levels of soil compaction * 9 nitrogen rates
1991/92	4 Pix strategies * 4 varieties * 3 Sowing dates

Each experiment was established as plots 8 rows * 20 metres and was monitored for vegetative growth. Harvest was by mechanical plot picker.

Results

In 1989/90, the experiment aimed to examine split applications in greater detail on all cultivars. Yield data is summarised in Table 2: there were only very small yield responses to Pix, and then only with DP90, and only with a single application. There was no interaction with nitrogen.

Table 2. Lint yield (kg/ha) of three cultivars in 1990 in response to various Pix application strategies. Average of two nitrogen rates (100 and 200 kg N/ha).

Treatment	Application dates	Siokra 1-4	Sicala 33	DP90
3*200 ml Pix/ha	Dec 6, 21, Jan 2	1951	1726	1691
2*300 ml Pix/ha	Dec 6 and 21	2007	1706	1679
1*600 ml Pix/ha	Dec 21	1909	1709	**1720**
1*1200 ml Pix/ha	Dec 21	1999	1733	1687
1*1200 ml Pix/ha	Jan 31	1867	1730	1644
Nil		**2014**	**1735**	1636

Dec 6: height 35 cm; 8 leaves. Dec 21: height 60 cm; 12 leaves.
Jan 2: height 75 cm; 14 - 15 leaves. Jan 31: height 91 - 105 cm; 22 leaves.

Pix did not enhance maturity date by more than two days, however there were more bolls set on the lower parts of plants which were treated with Pix (Table 3). In common with data from previous years, Pix reduced boll size.

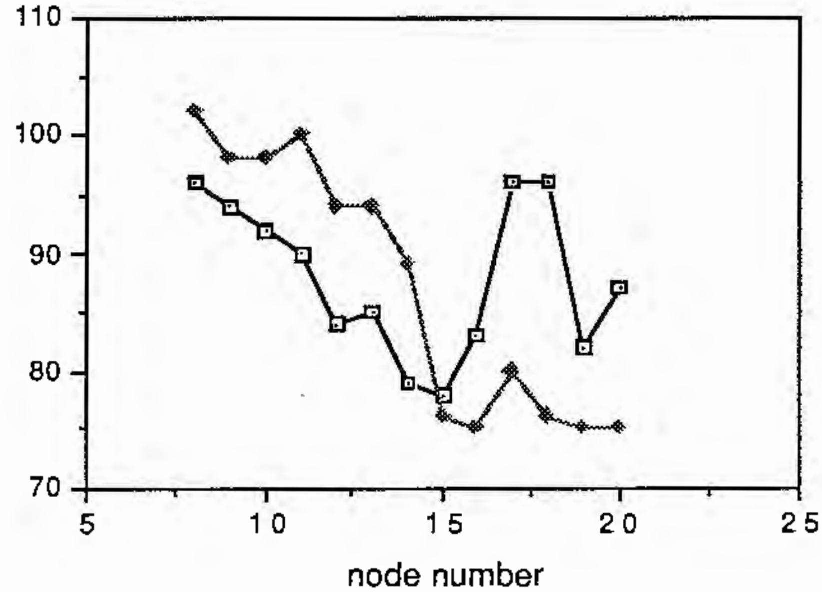
Table 3. Maturity and boll size in response to Pix

Date	% pickable by date		Boll size (g lint) by date	
	Pix	Nil	Pix	Nil
Feb 27	25	15	1.97	2.12
Mar 6	55	43	1.61	1.65
Mar 14	85	80	1.45	1.53
Mar 27	100	100	1.21	1.26

An experiment on narrow rows showed an increase in number of bolls set with split applications of Pix on narrow rows, but these bolls were significantly reduced in size compared with bolls from wide rows or no Pix.

DP90 had the greatest plant height response to Pix, with a reduction of 16 cm; achieved by a reduction in number of mainstem nodes (by one), and up to a 25% reduction in the length of internodes, particularly on upper nodes (Figure 1). When Pix was applied as split applications, starting at squaring, lower internodes were reduced in length more than when Pix was applied once at flowering (Figure 1). For all Pix application strategies, the nodes ultimately reduced in length were not visible at the time of application; this result emphasises the importance of application timing with Pix. *It is too late to apply Pix when plants are already tall.*

Figure 1. The relative length of mainstem internodes of DP90 as affected by Pix application strategy in 1989/90. Values are expressed as a percentage of internode length on untreated plants; solid line is for split Pix applications starting at squaring; grey line is for a single Pix application at flowering.



The same design was used in 1990/91. Yield data is summarised in Table 4: there were no responses to Pix; again there was no interaction with nitrogen.

Table 4. Lint yield (kg/ha) of three cultivars in 1991 in response to various Pix application strategies. Average of two nitrogen rates (100 and 200 kg N/ha).

Treatment	Application dates	Siokra 1-4	Sicala 33	DP90
3*200 ml Pix/ha	Dec 6, 20, Jan 10	2056	1794	1417
2*300 ml Pix/ha	Dec 6 and 20	2021	1828	1425
1*600 ml Pix/ha	Dec 20	2072	1833	1297
1*1200 ml Pix/ha	Dec 20	2004	1794	1505
1*1200 ml Pix/ha	Feb 4	2079	1865	1476
Nil		2046	1840	1533

An experiment was established to compare all combinations of Temik, Pix and Prep. Although Temik increased yield and Prep decreased yield, the results (Table 5) showed that there were no interactions - granular insecticide (Temik) did not establish a plant more responsive to Pix and Pix-treated plants are not more suitable for applications of the defoliant Prep.

Table 5. Lint yield (kg/ha) of DP90 in 1991 in response to Temik, Pix and Prep.

Treatments	No Pix		Pix	
	No Prep	Prep	No Prep	Prep
No Temik	1390	1366	1382	1307
Temik	1677	1591	1638	1510

Because nitrogen fertilizer levels had no effect on Pix response in either of the first two seasons, that treatment was dropped from the design in the 1991/92 season. Instead, sowing date was included as a factor to induce different rates of vegetative growth. Tables 6, 7 and 8 summarise the yield data from that experiment.

Best yields were obtained with October sowings and Siokra L22 was not suited to late sowing. Pix responses were greatest (25% yield increases) with late sowings; for earlier sowings Siokra L22 had the greatest yield response and Sicala 33 had the least.

Table 6. Lint yield (kg/ha) of four cultivars in 1992 in response to various Pix application strategies. Sown on October 8

Pix strategy	Application dates	Siokra 1-4	Siokra L22	Sicala 33	DP90
Split	Dec 5, 19, Jan 2	2740	2720	2518	2468
Single	Dec 19	2725	2835	2519	2571
Late	Jan 28	2812	2746	2519	2538
control		2780	2630	2531	2476

Table 7. Lint yield (kg/ha) of four cultivars in 1992 in response to various Pix application strategies. Sown on November 4

Pix strategy	Application dates	Siokra 1-4	Siokra L22	Sicala 33	DP90
Split	Dec 19, Jan 6, 20	2248	2457	2308	2313
Single	Jan 7	2503	2515	2244	2342
Late	Feb 7	2449	2528	2223	2290
control		2385	2615	2211	2335

Table 8. Lint yield (kg/ha) of four cultivars in 1992 in response to various Pix application strategies. Sown on December 3

Pix strategy	Application dates	Siokra 1-4	Siokra L22	Sicala 33	DP90
Split	Jan 20, 28, Feb 7	1462	1191	1441	1240
Single	Jan 28	1279	1206	1500	1269
Late	March 9	1311	1054	1353	935
control		1008	965	1226	1029

OVERALL SYNTHESIS OF PIX RESULTS

1. Strategy. Multiple applications have not been appropriate under any circumstances. Growers that are unsure as to the need for Pix may start early with a low rate and decide not to apply any more after further observation (save costs, save yield reduction). River soils that promote consistent vegetative growth may need multiple applications, especially in areas such as Biloela. There should be no need to apply Pix to rain-grown cotton unless there is excessive vegetative growth up to flowering.

2. Timing. The timing should coincide with when excessive vegetative growth is about to occur - not after. Choosing that timing will only come from accurate monitoring of the crop prior to flowering (see below). There was no advantage in applying Pix at cutout.

3. Rate. The rate should be proportional to the rate of vegetative growth of the crop. Following is an analysis of all data from this research.

The principle of monitoring and managing cotton crop vegetative growth has been examined in detail. Crops ranged in final plant height from 60 to 160 cm; and yields ranged from 5 to 11 bales/ha. In every experiment, the rate of internode increase in length has been measured prior to applications of Pix. The calculation was as follows:

$$\textbf{Rate of internode increase} = \frac{\textbf{This week's height - Last week's height}}{\textbf{This week's nodes - Last week's nodes}}$$

The results of that study are summarised in Figure 2. They show that internode increases of less than 5.5 cm lead to no response or even negative yield responses to Pix. Note that the standard Acala line used in California produces internode increases of more than 8 cm, so California should expect Pix responses - which is generally the case.

Since it is usually too late to obtain yield responses to Pix once a crop is already too tall, this procedure allows problem situations to be diagnosed before excessive vegetative growth occurs.

Figure 2 represents a principle that may apply across a wide range of seasons, soil types, sowing dates and varieties. Plants types which are smaller would generally not require Pix, unless they are sown late or are grown on light soil. Siokra 1-4, Siokra S324, Sicala 34, Sicala V1, CS 50 and CS 7S would all fit into the category of having a reduced Pix response. Siokra L22, CS 189 and DP90 are more vigorous and will respond to Pix more often.

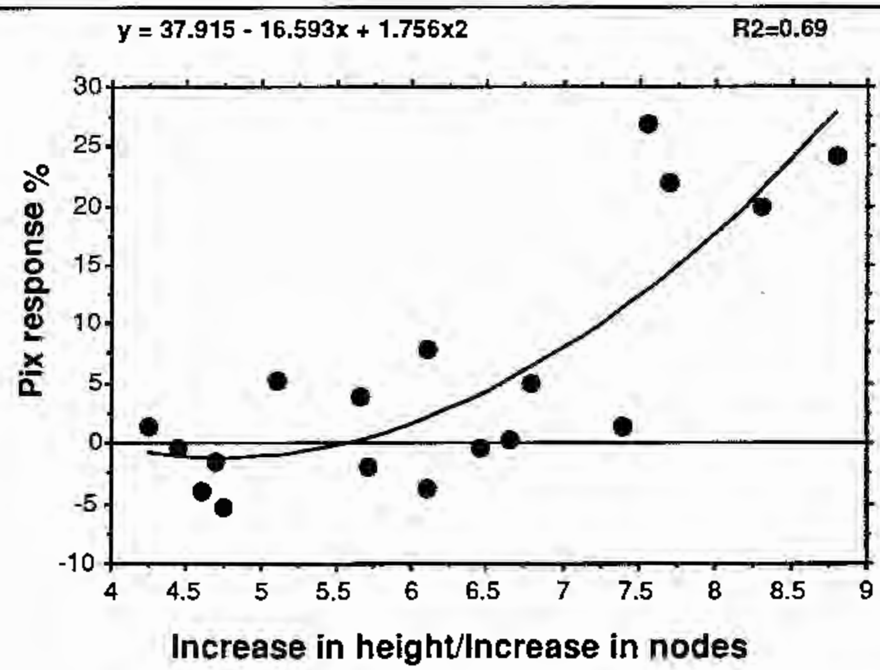


Figure 2. The relationship between rate of plant internode increase at early flowering and the subsequent yield response of that crop to Pix. Pooled data for three seasons and four varieties.

The results from Figure 2 can be used to make more informed decisions regarding the management of cotton vegetative growth. Table 9 summarises those decisions/actions.

Table 9. Using measurements of plant internode increase at early flowering to make decisions on Pix applications.

Rate of plant internode increase at early flowering stage.	Pix action	Other action/comments
less than 5.5 cm/node	nil	Encourage growth by judicious water and fertilizer management.
5.5 to 6.5 cm/node	200 ml/ha	Do not expect much Pix response.
6.5 to 7.5 cm/node	600 ml/ha	Continue good management.
greater than 7.5 cm/node	750 to 1200 ml/ha	Care should be taken with water and fertilizer management.

These experiments have shown that normal crops and varieties are in the category of growing at less than 6.5 cm/node; growth **encouragement** needs as much emphasis as growth regulation. Regular monitoring of plant size is the only way to accurately determine the need to manage crop growth.

B. Micronutrient disorders

Background

These projects aimed to examine two specific micronutrient disorders:

- The Galathera syndrome,
- Waterlogging induced iron chlorosis.

In each case, the extent of the problem in cotton is relatively small. However even that statement is vague because the true magnitude of each problem has not been determined accurately. Furthermore, this exercise is justified in terms of researching the nutritional relationships because the data will aid cotton fertilizer management in all areas, not just problem soils.

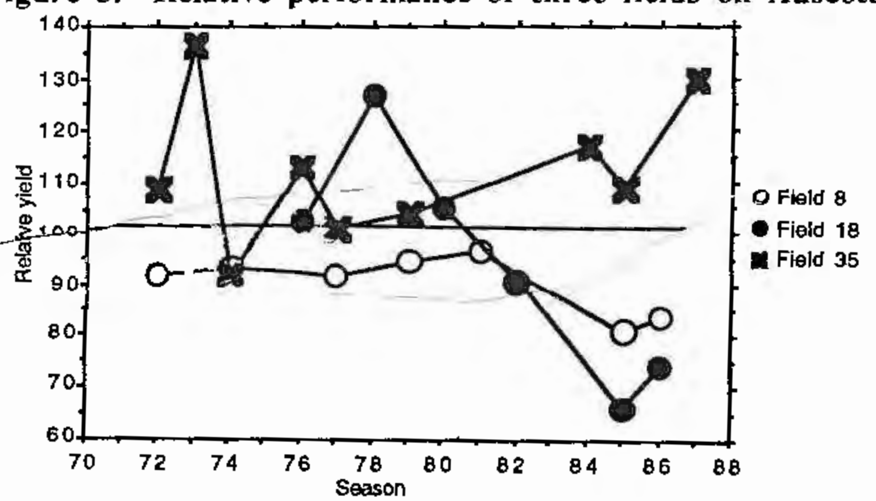
1. The Galathera syndrome

The Galathera Creek is a small occasional stream that has a few branches starting east of Edgeroi. Those streams meet before the Bald Hill road, and the Creek meanders through Auscott and Togo before petering out. During flood times, it pushes north-west through to the Moomin Creek (it can overflow into the Bobbiwaa Creek to the south). It is therefore part of the Gwydir catchment, even though it is only 5 km north of the Namoi River. There are occasional trees in the Creek, adjacent country has always been treeless.

When cotton was first grown adjacent to the Galathera Creek in the 1960's, there was a cotton bounty, low costs, and yield targets / expectations were low; five bales per hectare was seen as a good crop. The seasons were relatively dry, there was no disease and the cropping system was three years cotton followed by wheat. Within ten years, two diseases (verticillium wilt and bacterial blight) and soil compaction had prompted a cotton-wheat rotation. Despite improved varieties the yield plateau of 5 to 6 bales ha^{-1} has remained. Other crops such as wheat, corn and sunflower do not appear to be affected.

Seed germination and emergence of cotton in October is normal, but subsequent seedling growth is very slow, with delayed squaring. Plant growth is stunted, with small leaves and short internodes. Leaf symptoms include cupping, interveinal chlorosis, and burning, browning or bronzing of the leaf margins. Measurements of petiole nitrate during November show low values at all N fertiliser rates. The delayed growth of cotton seems to make the plants more susceptable to Verticillium wilt. In December, plant vegetative growth speeds up, ultimately producing normal-sized plants but with delayed maturity and low yield. Figure 3 demonstrates the range in performance of different fields.

Figure 3. Relative performance of three fields on Auscott.

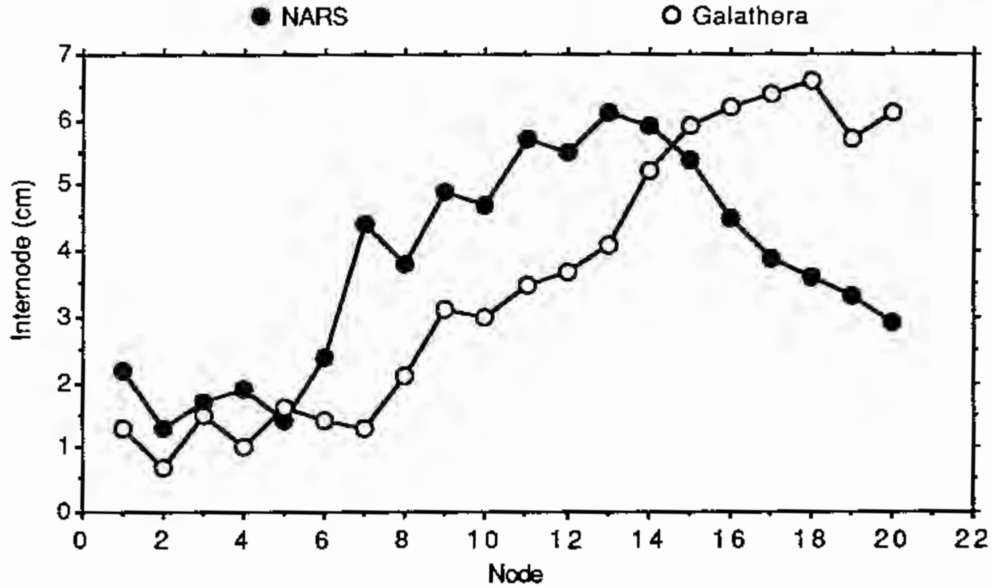


Field 35 is a consistently good performer; the low yield in 1974 could be attributed to having had three years of cotton without any fallow, plus flooding damage. Field 8 is a consistently bad performer; always having below average yields. The north end of field 8 is particularly bad. Fields 19 and 20 are also consistently poor performers. Field 18 is adjacent to Galathera Creek, the records show that this field is getting worse. Some areas in fields 8, 17, 19 and 20 can be particularly bad, with seedling death being common - these bad areas form a contiguous path meandering through a field as if it were associated with a prior creek bed.

Preliminary crop observations

Normal plants have short internodes at the base of the stem, longer internodes in the middle of the plant when rapid growth starts prior to flowering, then shorter internodes at the top of the plant as it cuts out. Plants with the Galathera syndrome do not have longest internodes in the middle of the plant, emphasising the delayed and restricted vegetative growth prior to flowering. The longest internodes are at the top of Galathera syndrome plants (Figure 4).

Figure 4. Comparison of internode lengths of cotton plants on the Research Station (NARS) and Galathera.



Normally, petiole nitrate starts at a high level and declines at a regular rate. Galathera plants have a low petiole nitrate level as young seedlings. These differences are shown in Figure 5; note higher fertilizer rates increase the level of petiole nitrate, but do not prevent the low levels in young plants.

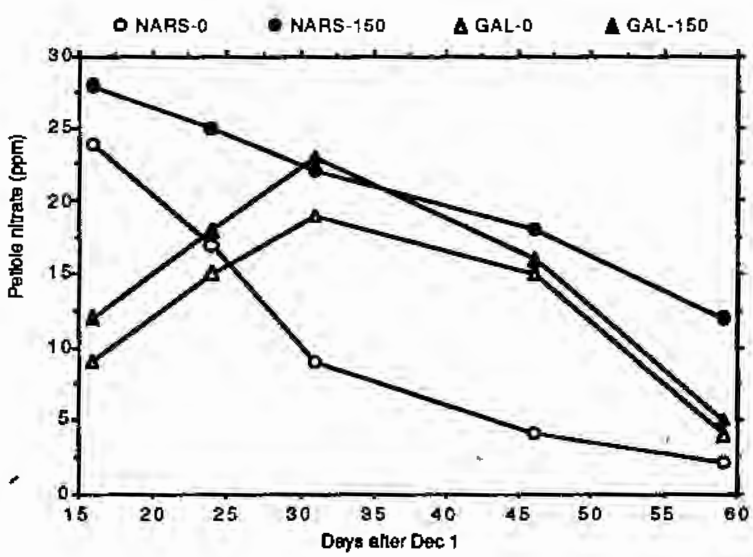


Figure 5.

Petiole nitrate patterns on the Research Station (NARS) and on Galathera (GAL). There were two fertilizer rates at each site.

In the 1984/85 season, a survey was done on 35 fields of cotton to establish levels and ranges for trace elements. Leaf blades were sampled in January; whole plant samples were taken in February for total uptake. Some fields on Auscott were included in that survey. The results showed the sampled fields were typical of average cotton, except perhaps for lower zinc levels and zinc uptake. Unfortunately, no Galathera problem fields were included in the survey.

Further leaf tissue samples were taken in February 1988 to establish a base for all elements and also to compare Auscott with the Research Station (Field C4) where no nutritional disorders are suspected. Potassium levels were relatively low, creating a low K/Mg ratio. Some phosphorus levels were low, which was surprising because soil P levels are high. Zinc levels were also low on fields 6, 9 and 10. Comparison with NARS shows lower P and much higher Mn.

Soil description

McGarry et al (1989) investigated the relation of the cracking clay soils to the landscape and its geomorphic history. The residual rocks form the Nandewar ranges to the east, they include basalts and sandstones (Ward et al 1988). They are not thought to have given rise to extensive areas of soil. Instead, it is believed the soils on the plains are derived from colluvium (hill wash), alluvuim (river and stream sediment) and Aeolian dust deposits. The Galathera Creek represents a boundary in heavy floods between local alluvium from the Nandewars and alluvium from the Namoi River.

Table 10. Chemical and particle size analysis (after McGarry et al 1989)

Depth cm	pH	EC mSm^{-1}	org C %	$CaCO_3$ %	clay %	cl^- $mg\ kg^{-1}$	P	Ca $mmol\ kg^{-1}$	Mg	K	Na
0-10	8.6	12.8	0.75	0.4	64	20	25	268	183	16.7	24.3
10-20	8.8	12.1	0.56	0.3	66	8	18	276	181	15.4	26.9
30-40	9.1	22.9	0.41	0.7	63	7	12	256	195	10.8	56.8

Parent rock - alluvial sediment, clay. Small flecks of manganese below 200 cm. Old alluvuim.
Soil classification: Principal profile form: Ug5.16; Great soil group: Grey clays;
Soil taxonomy unit: Pellusterts

Detailed soil tests in problem areas

Soils on Galathera are 'puggy', being soft and sticky when wet, but hard and cracked when dry. The data (Table 11) indicate no major problems, except for low soil zinc in field 20. Because of the possibility of poor mycorrhizal infection affecting phosphate availability, a number of different soil P extractions were performed at Tamworth Agricultural Research Centre by Barry Schweitzer (Ian Holford group). Their comment was that all soils were high in phosphate (as measured by all types of chemical extraction) - especially Fields 19 and 20 - the Galathera sites.

Table 11. Soil test results obtained in 1988, in a comparison between Galathera problem fields and the Research Station (R). The north end of fields 8 and 20 contain the worst examples of Galathera syndrome. Sample depth was 0-30 cm.

Measure	units	8N	8S	20N	20S	R-18	R-D2	R-C1
pH	in water	7.8	8.1	8.0	7.9	7.7	8.2	7.9
P	ppm	51	39	72	59	49	18	61
K	meq	1.23	1.25	1.70	1.46	1.30	1.39	1.60
Ca	meq	15.1	18.8	25.8	18.8	24.9	24.6	23.7
Mg	meq	10.5	10.8	11.5	10.5	10.4	12.5	10.0
Na	meq	1.06	0.60	1.48	1.15	0.44	1.28	0.74
CEC	meq	27.9	31.4	40.5	31.9	37.0	39.8	36.0
cl	ppm	20	10	15	15	5	5	35
Cu	ppm	0.6	0.7	0.7	0.5	1.6	1.2	1.9
Zn	ppm	0.4	0.3	<0.1	0.2	2.3	6.7	3.2
Mn	ppm	2	1	3	1	7	8	12
Fe	ppm	12	9	12	6	30	17	20
B	ppm	0.5	0.6	0.4	0.5	0.3		0.3
ESP	%	3.8	1.9	3.7	3.6	1.2	3.2	2.0
EC	mS/cm	.10	.07	.10	.09	.11	.12	.15

Series 1 experiments, 1988/89

In August 1988, experiments were set up on Auscott fields 4, 7 and 8 to evaluate crop response to phosphorus, potassium, zinc and copper. The experiment was a 2^3 factorial with all combinations of plus or minus phosphorus, potassium or zinc+copper. There were four replications on plots 8 rows x 17 metres. P was applied at 20 kg P ha^{-1} as double super; K was applied at 60 kg K ha^{-1} as potassium chloride; Zn was applied at 4 kg Zn ha^{-1} as zinc chelate; Cu was applied at 2 kg Cu ha^{-1} as copper sulphate. All treatments were applied as a band under the crop row.

Field 8 showed classic and chronic Galathera symptoms as described above. Seedling death of the commercial cotton in field 8 was so bad that some replanting was necessary.

There were no visual responses to any treatment in any field. Yield results for these experiments are as follows:

Table 12. Effect of factorial combinations of phosphorus (P), potassium (K) and trace elements (T = Zn + Cu) on seed cotton yield on the Research Station and on three Auscott fields. Superscripts are the relative yield of the highest and lowest yielding treatment at each site.

	Seed cotton yield (kg/ha) at four sites				
Treatment	NARS-C1	Aus-4	Aus-7	Aus-8	Mean
nil	5130^{106}	4654	4744	3603	4533^{103}
P	4930	4172^{93}	4841	3200	4286^{98}
K	4883	4469	4685	3791^{110}	4457
T	4513^{94}	4619	4900	3490	4381
PK	4711	4225	5013^{104}	3771	4430
PT	4974	4493	4874	3012^{88}	4338
KT	4899	4682^{104}	4612^{96}	3250	4361
PKT	4555	4643	4774	3365	4334
mean	4824	4495	4805	3435	4390

There were no significant responses and the nil treatment had the best mean yield.

Each plot was sampled three times during the season for leaf or plant nutrient status. The youngest fully expanded leaf was sampled on December 20 and January 18. Each sample of 30 leaves was washed in distilled water before drying and grinding. A 1 m^2 quadrat was sampled in February for total nutrient uptake. These data are presented in the following tables; nutrient content in leaf blades is expressed as % for N, P, K, Ca, Mg and S; as ppm for Mn, Fe, Zn and Cu. Uptake is expressed as kg ha^{-1} for N, P, K, Ca, Mg and S; and as g ha^{-1} for Mn, Fe, Zn and Cu. Each table is followed by description of statistically significant differences, if they occurred.

Table 13a. Field 4 (long-term yield of 106%)

Part	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
leaf	Dec 20	4.10	.36	1.97	3.11	.61	.74	118	120	22	9
leaf	Jan 18	4.98	.45	1.50	2.65	.55	.87	136	156	28	12
uptake	Feb 8	121	13	139	86	25	19	309	414	99	48

For the samples taken on Dec 20, addition of Zn+Cu increased Zn content from 20 to 24 ppm; increased Cu from 8.6 to 9.8 ppm; and decreased P from 0.38 to 0.35%. These effects were significant at the 0.01 level. For the samples taken on Jan 18, addition of K increased K content from 1.47 to 1.53% ($P<0.01$). None of the treatments significantly affected nutrient uptake.

Table 13b. Field 7 (long-term yield of 96%)

Part	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
leaf	Dec 20	4.16	.32	2.14	2.91	.56	.59	126	159	21	7
leaf	Jan 18	4.24	.28	1.50	1.77	.40	.47	101	76	19	10
uptake	Feb 14	121	17	145	105	26	25	406	314	169	39

The addition of Zn+Cu reduced Mn content from 131 to 121 ppm on Dec 20; and from 107 to 94 ppm on Jan 18 ($P<0.01$). For total plant uptake in February, the addition of P decreased N uptake from 130 to 113 kg ha^{-1}.

Table 13c. Field 8 (long-term yield of 91%)

Part	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
leaf	Dec 20	4.45	.36	2.27	3.44	.67	.65	147	256	26	11
leaf	Jan 18	5.24	.36	1.77	2.48	.56	.62	133	116	33	-
uptake	Mar 1	153	21	169	113	31	29	434	329	128	54

The addition of Zn+Cu reduced Mn content from 147 to 120 ppm and increased iron content from 104 to 128 ppm on Jan 18 ($P<0.001$).

Table 13d. Field C1 on Research Station

Part	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
leaf	Dec 6	4.06	.31	1.90	4.08	.68	.74	114	96	33	19
leaf	Jan 20	4.61	.43	1.22	2.08	.43	.58	41	56	30	8
uptake	Jan 30	177	25	202	125	36	35	228	308	232	74

There were no significant responses to these treatments. It is of interest to note higher Mn levels, Mn/Zn ratios and Mn uptake at Auscott compared with the Research Station.

Actual levels of all nutrients in each field were within established sufficiency guidelines. For a true zinc deficiency, zinc application should be at higher rates (10-20 rather than 4 kg Zn ha^{-1}) and throughly incorporated, rather than banded. That strategy was followed in later experiments.

Experiment 2, 1988/89

In November 1988, following the observation of chronic zinc deficiency symptoms on Auscott field 20 (long-term yield of 78%), a foliar zinc experiment was established. A preliminary tissue sample showed relatively low zinc levels. High levels of phosphorus, iron and manganese and low levels of zinc were evident (Table 14).

Table 14. Leaf tissue analysis from field 20, November 1988 (units as before).

N	P	K	Ca	Mg	S	Na	Cl	Mn	Fe	Zn	Cu	B	Al
4.64	0.59	2.55	3.65	0.81	0.80	0.15	1.24	287	383	15	15	66	331

Treatments comparing different rates and forms of foliar zinc were applied by hand boom on 24/11/88, at 300 l ha^{-1}; a wetting agent was included. Plot size was 3 rows x 15 m; there were three replications. Each plot was sampled during the season for leaf or plant nutrient status. The youngest fully expanded leaf was sampled on December 20. Each sample of 30 leaves was washed in distilled water before drying and grinding. A 1 m^2 quadrat was sampled in February for total nutrient uptake.

Table 15. Average leaf tissue analysis from the experiment in Field 20, December 1988; and subsequent uptake of nutrients in late January 1989 (units as before).

part	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
leaf	Dec 20	5.53	0.65	1.62	3.41	0.54	1.10	220	103	29	7.2
uptake	Jan 30	82	11	89	74	16	16	317	258	80	14

The recovery of applied zinc was very low (the standard error for zinc uptake was 17 g ha^{-1}, so recoveries less than 3.4% were not detectable). Uptakes were low because the plants were relatively small. The only measurement that was statistically significant was the leaf concentration of P on December 20: one foliar zinc treatment reduced leaf P concentration (Table 16):

Table 16. Effect of foliar Zn on leaf P concentration

Treatment	$ZnSO_4.7H_2O$		Zinc chelate		Zintrac		nil
Zn applied (g ha^{-1})	200	1000	200	1000	200	1000	0
P content (%)	0.69	0.64	0.67	**0.54**	0.65	0.63	**0.70**

Although there was no apparant visual response to these treatments, at harvest there was a 9 to 12% yield increase to 200 g ha^{-1} of foliar zinc, albeit at a fairly low yield level. High rates of zinc sulphate and zinc chelate decreased yield (Table 17).

Table 17. Yield response to foliar zinc on field 20. (soil Zn: <0.1 ppm; leaf Zn: 15 ppm).

Form	Rate (g ha^{-1})	Seed cotton (kg ha^{-1})	Rel yield (%)
$ZnSO_4.7H_2O$	200	5250	**112**
	1000	4180	89
Zn chelate	200	5258	**112**
	1000	4643	99
Zintrac (ZnO+N)	200	5095	**109**
	1000	5117	**109**
Control	0	4687	100
se diff		306	

Series 3 experiments, 1989/90

In 1989, further experiments were set up on Auscott fields 6, 19 and 35 to evaluate rates, forms and strategies of applying zinc. Further treatments tested gypsum, lime, potassium and a combination of phosphorus, manganese and sodium. Note field 19 is in a Galathera problem area with a yield record of 82%. The treatments were set up in late winter-early spring. Because of the wet winter, the soil zinc treatments were not incorporated as early as desirable. Plots were 8 rows x 17 m; there were three replications.

Treatments imposed on those fields are shown in Table 18.

Table 18. Treatments applied in 1989/90

no	treatment	rate ai (kg ha^{-1})
1	nil	
2	Soil zinc sulphate	10
3	Soil zinc sulphate	20
4	Soil zinc sulphate	30
5	soil zinc oxide	10
6	soil zinc chelate	10
7	soil zinc sulphate + foliar zinc	10 + 0.2
8	foliar zinc	3 x 0.2
9	foliar zinc	1x 0.2
10	soil potassium sulphate	100
11	soil potassium sulphate	500
12	foliar potassium	10
13	gypsum	7500
14	gypsum + soil zinc sulphate	7500 + 10
15	lime	4400
16	soil copper	5
17	bad = Mg + Na + P + Mn	100+100+50+0.1

Again, none of the treatments created visual plant responses at any stage.

Field 19 had very severe Galathera symptoms of stunting and even seedling death. Samples of leaf tissue from field 19 at this time (November) showed the following results (Table 19):

Table 19. Comparison between two categories of plants from field 19 in 1989.

Category	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
better plants	4.28	.33	1.56	3.74	.64	.56	131	125	18	8
worst plants	4.36	.23	1.11	3.08	.64	.49	126	140	9	6

The greatest differences between better and worst plants were large reductions in zinc, phosphorus and copper; and a slight increase in iron. The subject of vesicular arbuscular mycorrhiza (VAM) in relation to the Galathera syndrome is covered in a later section.

As in the previous season, all plots of each experiment were sampled for leaf or total plant nutrient levels. Units are the same as in previous tables; all uptakes are reduced by severe hail damage.

Table 20a. Field 6 (long term yield of 95%)

part	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
leaf	Dec 13	5.34	.43	2.05	4.01	.56	.91	124	103	30	9
leaf	Jan 18	3.57	.40	1.57	2.40	.35	.65	90	70	23	8
uptake	Feb 28	88	17	108	65	15	18	170	221	95	29

Gypsum treatments increased leaf tissue sulphur by 50 to 150% ($P<0.01$). Foliar zinc reduced Mn uptake from 192 to 135 g ha^{-1} and P uptake from 18 to 14 kg ha^{-1} ($P<0.05$). No other treatments significantly affected plant nutrient content or uptake.

Table 20b. Field 19 (long term yield of 82%)

Field	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
leaf	Dec 14	4.83	.34	1.50	3.85	.69	.78	168	227	19	7
leaf	Jan 12	4.45	.52	1.82	2.87	.54	.84	169	92	23	8
uptake	Mar 5	82	9	31	141	10	14	618	187	35	11

Again, gypsum increased sulphur content ($P<0.001$) but not uptake. Foliar zinc increased leaf tissue zinc from 15 to 24 ppm ($P<0.05$) at the first sample date only. At this date the manganese treatment increased Mn from 154 to 173 ppm ($P<0.05$).

Table 20c. Field 35 (long term yield of 112%)

Field	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
leaf	Dec 13	5.50	.46	1.92	3.62	.70	.85	96	116	27	10
leaf	Jan 10	5.30	.48	1.70	2.76	.68	.72	105	130	25	9
uptake	Feb 13	145									

Gypsum increased sulphur levels at both sampling dates by 70% ($P<0.001$). The soil zinc treatment decreased Fe from 143 to 125 ppm ($P<0.05$).

Table 20d. Field 4 - Research Station

part	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
leaf	Dec 11	5.03	.35	1.49	3.31	.84	.76	70	112	36	13
leaf	Jan 10	4.48	.45	1.52	2.96	.66	1.06	66	109	42	9
uptake	Feb 7	133									

Again, gypsum increased sulphur content ($P<0.001$). No other treatments significantly affected plant nutrient content.

There were no statistically significant results at any site. Fields 6 and 19 had a 7% yield increase in response to foliar zinc; consistent with the slight increase achieved the previous year in field 20 The overall yield levels (kg seed cotton/ha) were: Field 6 - 1782; Field 19 - 1060; and Field 35 - 2729; those yields indicate the severity of hail damage.

Table 21. Average yield from 3 fields on Auscott and from field 4 on the Research Station.

Treatment	Auscott fields Seed cotton yield (kg/ha)	Auscott fields %	Research Station Seed cotton yield (kg/ha)	Research Station %
Control	2015	100	3820	100
Soil zinc	2071	103	-	-
Foliar zinc	1982	98	3740	98
Soil potassium	2050	102	3870	101
Foliar potassium	1861	92	3680	96
Gypsum (7.5 t/ha)	2003	99	3700	97
Lime (4.4 t/ha)	1878	93	3800	99
Copper (5 kg/ha)	2129	106	3920	103
P + Mg + Mn	1872	93	3780	99

Cultivars

A group of 16 cultivars were sown on Field 19 to determine whether early growth or plant tissue levels were affected by cultivar. The cultivars were:

From Australia:	Siokra 1-4, Siokra 324, Namcala seln, 83055-33, Sicala 3-2, Sicala 33
From USA:	Deltapine Smoothleaf, Deltapine 90, Tamcot CAMD-E, Paymaster 145, Coker 315, PD-9363, GC-510, Cascot 002
From Africa:	Bar 7/8
From Russia:	HN-402

Although there were no measureable differences in early growth, there were small differences in tissue levels: Coker 315 was higher in Mg and Zn; and lower in Mn than Deltapine and Siokra cultivars.

Table 22. The range in tissue Mn and Zn levels across cultivars; field 19, 1989/90.

Cultivar	Manganese (ppm)	Zinc (ppm)	Mn/Zn ratio
DP90	167	21	8.0
Siokra 1-4	156	23	6.8
Coker 315	142	26	5.5

We have introduced a manganese tolerant Coker line (Coker 310-73-307) through quarantine from South Carolina for sowing and crossing with local varieties in the 1991/92 season. F2 progeny rows from those crosses are being evaluated in 1992/93 at the Research Station and on Galathera.

Series 4 - Mycorrhizae experiments

Because some of the symptoms resembled descriptions of vesicular arbuscular mycorrhiza (VAM) deficiency, roots from field 19 in 1989/90 were assayed for VAM infection. Those results showed that at 6 weeks, only 29% of roots of plants from field 19 were infected with VAM, whereas normal seedlings from the Research Station had 72% of roots infected. Even at 10 weeks, roots from plants from field 19 still only had 46% infection with VAM.

We were able to duplicate Galathera symptoms on Research Station soils by sterilization with methyl bromide. The following (Table 23) shows leaf tissue tests and root mycorrhizal counts from a few sites in the 1989/90 season. Plants in these fields showed varying degrees of delayed growth and development as seedlings.

Table 23. Induction of Galathera symptoms with soil sterilization. Field 14 is on Narrabri Agricultural Research Station (average of two sowing dates); + or - refer to methyl bromide sterilization treatments. Also shown are assessments of plants from Brewarrina with (fields 18,27) or without long-fallow disorder.

		NARS field 14		Brewarrina (field nos)		
	units	+	-	18	27	23/13/14
N	%	4.3	4.7	3.7	3.3	3.4
K	%	1.6	2.0	1.4	1.2	1.3
Ca	%	3.6	3.7	3.0	2.8	3.2
P	%	.14	.36	.15	.11	.19
Mg	%	.62	.61	.55	.56	.58
S	%	.83	.72	.41	.34	.53
Fe	ppm	172	92	53	75	44
Mn	ppm	95	57	95	105	119
Zn	ppm	18	29	13	5	15
B	ppm	115	44	64	65	53
Cu	ppm	10	14	11	10	9
VAM 6w	% roots	4.3	64.0	20.2	15.6	60.9

The greatest differences induced by soil sterilization have been reductions in P and Zn, and increases in Mn, Fe and B. VAM infection was least on plants in sterilized soil.

In 1990/91, the VAM treatments consisted of soil sterilization, combined factorially with VAM inoculation and zinc+phosphate fertilizer treatments. Plot size was restricted to 1 m. The Galathera syndrome is expressed most at the young seedling stage where buffered plots are not necessary; plots of that type are impossible to assess for crop yield. Assessment of treatments in that experiment had to be based on plant height.

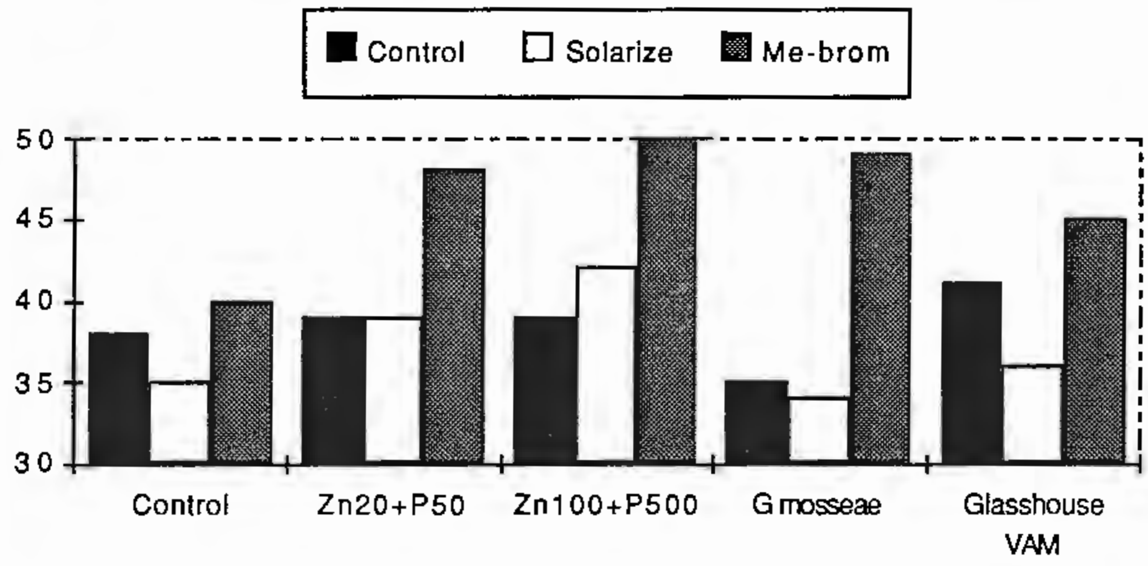
Plant height measurements of those experiments showed that soil sterilization with methyl bromide allowed cotton plants to grow faster. Home-grown VAM (soil from under cotton at NARS - used to grow glasshouse maize) produced taller plants with no soil sterilization. High fertilizer rate and *Glomus mosseae* treatments also gave plant height increases on sterilized soil.

Table 24. Plant heights in 1990/91 mycorrhiza experiment.

	Nov 11, 1990				Jan 7, 1991			
Sub-plot	Control	Solarize	Me-br	Mean	Control	Solarize	Me-br	Mean
Control	11	10	15	12	38	35	40	38
Zn20+P50	11	11	16	13	39	39	48	42
Zn100+P500	11	12	16	13	39	42	50	44
G mosseae	11	11	16	12	35	34	49	39
G'house VAM	13	12	14	13	41	36	45	41
Mean	11	11	15		39	37	46	

For Nov: standard error of difference for s.m=1.2*, for s=0.6ns, for m=0.7***
For Jan: standard error of difference for s.m=2.7*, for s=1.6**, for m=1.7***

Figure 6. Plant height of cotton in response to soil sterilization and a range of zinc + phosphate fertilizer or VAM inolulation treatments. Measurements taken on January 7, 1991.



Comments:

1. In untreated soil, glasshouse VAM has significantly improved growth over *G mosseae*. The local organisms appear to be better adapted to local conditions. It is also possible that the local VAM mix contained plant growth promoting rhizobacteria.

2. Sterilization with methyl bromide has improved early season growth of cotton on a Galathera site. It is possible that MeBr has removed deleterious rhizosphere microorganisms that inhibit VAM colonisation. Other effects could be due to reductions in specific cotton root pathogens.

3. On sterilized soil, *G mosseae* was at least as effective as 20 kg Zn and 50 kg P per hectare.

4. Sterilization with MeBr on a non-Galathera site reduces cotton growth due to reductions in VAM (and possibly plant growth promoting rhizobacteria). See Table 18 for plant heights at a later date on a zinc fertilizer experiment.

Series 5 experiments, 1990/91

In the spring of 1990, experiment was established on Auscott field 19 to further examine the interaction between phosphorus, zinc and manganese. Rotation experiments were also set up on fields 17 and 19 to further explore VAM issues.

Our advise on demonstrating the lack of vesicular arbuscular mycorrhiza (VAM) infections on field crops is to apply both phosphorus and zinc at high rates. This experiment has those nutrients applied at zero, medium and extreme rates. A foliar zinc treatment was also included (200 g Zn/ha, applied on Dec 13). Some plant tissue analyses of problem plants from this area have shown very high levels of manganese, possibly from Mn being released from a long history of flooding at this location. A treatment was included which should generate a range of Mn levels. Plots were 8 rows x 14 metres.

Observations were noted on Jan 14 because of differences in symptoms and plant height.

Table 25. Leaf colour-symptom score on Jan 14. 1=normal, 2=slight interveinal chlorosis, 3=interveinal chlorosis, 4=interveinal chlorosis and leaf cupping.

	Phosphorus (kg/ha)		
Zinc (kg/ha)	0	50	500
0	**2.8**	**3.0**	**3.9**
20	**1.0**	**1.3**	**1.4**
100	**1.0**	**1.2**	**1.2**
Manganese at 100 kg/ha:	**3.1**		
Foliar Zn at 200 g/ha:	**2.3**		

Table 26. Plant height (cm) on January 14, 1991.

	Phosphorus (kg/ha)		
Zinc (kg/ha)	0	50	500
0	**51**	**53**	**51**
20	**58**	**58**	**57**
100	**57**	**58**	**56**
Manganese at 100 kg/ha:	**50**		
Foliar Zn at 200 g/ha:	**55**		

High rates of phosphorus and manganese have exaggerated Galathera symptoms. Zinc can alleviate those symptoms if induced by P. Note that these symptoms were not as evident two weeks later.

Tissue samples (leaf and whole plant) measured whether and when Zn, P and Mn treatments were being taken up.

Table 27. Results of tissue analyses from field 20 in 1990/91.

Part	Date	N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
Leaf	Dec 24	4.69	0.38	2.13	3.24	0.56	0.80	135	103	25	8.5
Leaf	Jan 14	4.85	0.50	1.69	3.01	0.49	0.91	155	86	32	8.1
Uptake	Mar 20	135	22	129	108	25	32	421	577	116	42

These tissue data showed the following consistent (two dates) and significant ($P<0.05$) effects:

- Phosphorus fertilizer increased P, Mn and S tissue levels.

kg P/ha	P(%)	Mn (ppm)	S (%)
0	.41	140	.79
50	.44	147	.81
500	.48	148	.97

- Zinc fertilizer increased Zn and decreased P and Mn levels.

kg Zn/ha	Zn (ppm)	P (%)	Mn (ppm)
0	21.6	.46	158
20	28.6	.43	145
100	30.4	.41	132

• Plant nutrient uptakes showed that zinc and manganese fertilizer treatments were effective in increasing uptakes of those nutrients. Zinc fertilizer affected P uptake erratically.

kg Zn/ha	P uptake (kg/ha)	Zn uptake (g/ha)
0	111	98
20	105	117
100	131	131

kg Mn/ha	Mn uptake (g/ha)
0	323
100	550

Since the Mn treatment did not affect Mn content of leaves in December or January, the greater uptake of Mn in the Mn treatment was due to either accumulation of Mn in plant stems and/or to enhanced uptake during February and March.

Two rows from each plot were harvested on April 23. After weighing, a subsample was taken from each plot for ginning. The manganese treatment had the lowest yield (see Figure 7). This result is consistent with visual symptoms (Table 25). Harvest index (lint yield/total dry weight) was particularly low in this treatment (12% v 19%). The strongest positive effect in the data was a 9.5% yield increase with zinc at 20 kg/ha soil applied (Figure 8). Part of that increase was associated with slightly higher harvest index (1% unit higher) and higher gininning percentage (0.6% units higher). Foliar zinc treatments were not successful this year, despite good dry weight responses (low harvest index).

Figure 7. Lint yields of all treatments in 1990/91.

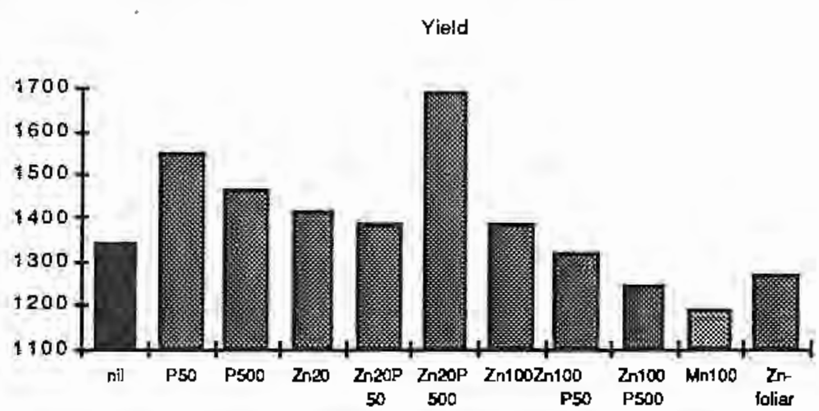
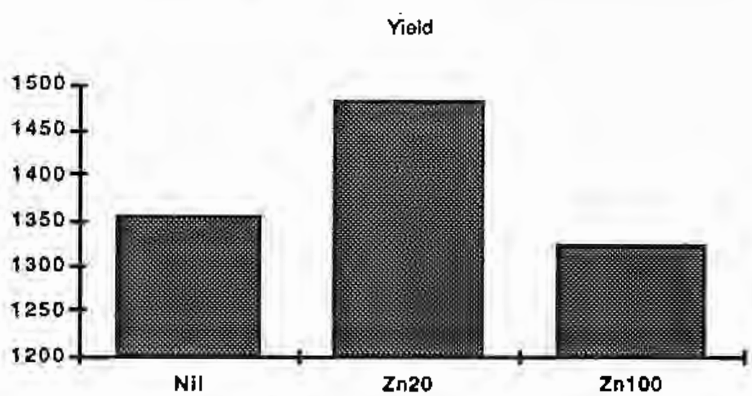


Figure 8. Main effect of soil zinc on lint yield.



The project in 1991/92 included a study of the carry-over of treatments from the previous season on a problem Galathera field: The experiment was a factorial of three soil Zn levels by three soil P levels, plus Mn and foliar Zn treatments.

Table 28. Overall mean tissue levels from field 20 in 1991/92.

P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Mn/Zn
.38	1.54	3.02	.56	.78	84	147	32	8	4.7

The following notes emphasise significant treatments effects on leaf tissue:

- Sulphur. Phosphate treatments increased S levels - because S was supplied with P.

P rate (kg/ha)	S (%)
0	0.73
50	0.75
500	0.85
sed	0.019

- Manganese. Manganese treatment and zinc treatments affected Mn levels.

Mn rate (kg/ha)	Mn (ppm)	Zn rate (kg/ha)	Mn (ppm)
0	150	0	152
100	157	20	151
		100	138
sed	7.2		4.7

- Zinc. Phosphorus and zinc treatments affected zinc levels in leaf tissue. No interactions.

P rate (kg/ha)	Zn (ppm)	Zn rate (kg/ha)	Zn (ppm)
0	33	0	28
50	32	20	32
500	30	100	36
sed	0.9		1.0

- Copper. Phosphorus treatments decreased copper levels in leaf tissue.

P rate (kg/ha)	Cu (ppm)
0	8.6
50	8.0
500	7.4
sed	0.4

- Manganese/zinc ratio. Zinc treatments reduced the Mn/Zn ratio.

Zn rate (kg/ha)	Mn/Zn ratio
0	5.5
20	4.7
100	3.9
sed	0.20

Yield was measured by harvesting 26 m^2 from each plot. Statistical analysis showed that Zn treatments were the only factor affecting yield - there was not response to P and no interaction between P and Zn.

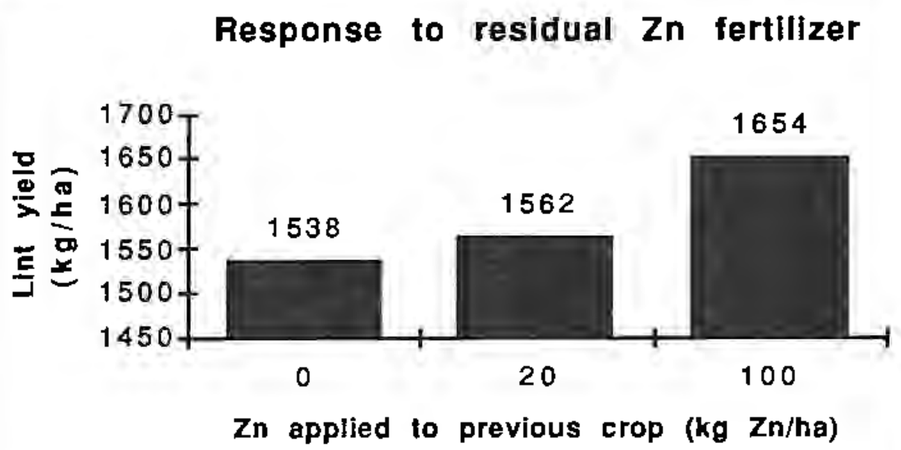


Figure 9. Response of cotton to residual Zn fertilizer. The Zn treatments were applied in winter of 1990; the 1990/91 crop had a significant response to 20 kg Zn/ha. These data are for the 1991/92 season, showing a significant response to 100 kg Zn/ha.

At cotton prices of $350 per bale these responses to 20 and 100 kg Zn/ha are worth $37 and $179 /ha respectively. Even if Zn cost $2 /kg, these responses would not be economic in the first year. However the *two year cumulative increase* with 20 kg Zn/ha is 110 kg lint/ha, worth $169/ha, which would be very economic.

Trends in plant Zn level over the past five seasons

The graph below shows the trend in leaf Zn level on Galathera fields in the past 5 seasons. The improvement in level has been consistent - these values are not necessarily due to Zn fertilization, in fact it is more likely the trend is due to changes in management practices such as tillage and crop rotation.

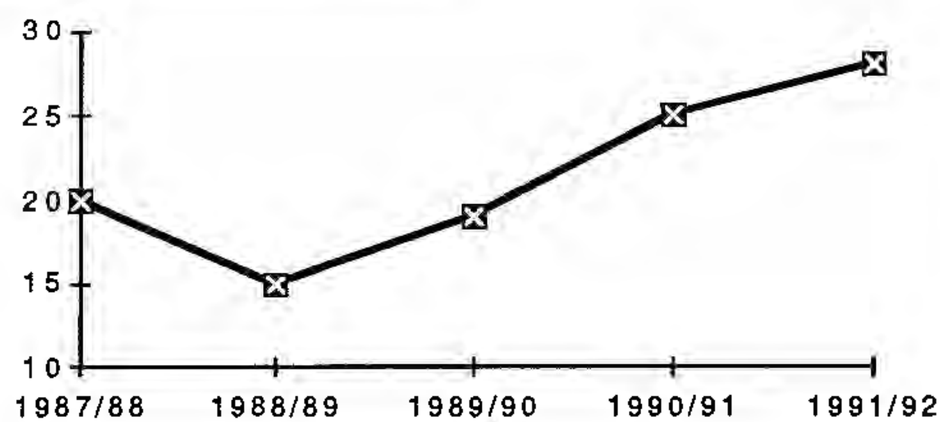


Figure 10. Pattern of leaf blade Zn content (ppm) measured at late squaring to early flowering of cotton crops in the Galathera area.

In 1991/92 Auscott set up a rotation experiment on a Galathera site. Those results are shown in the following Figure 11.

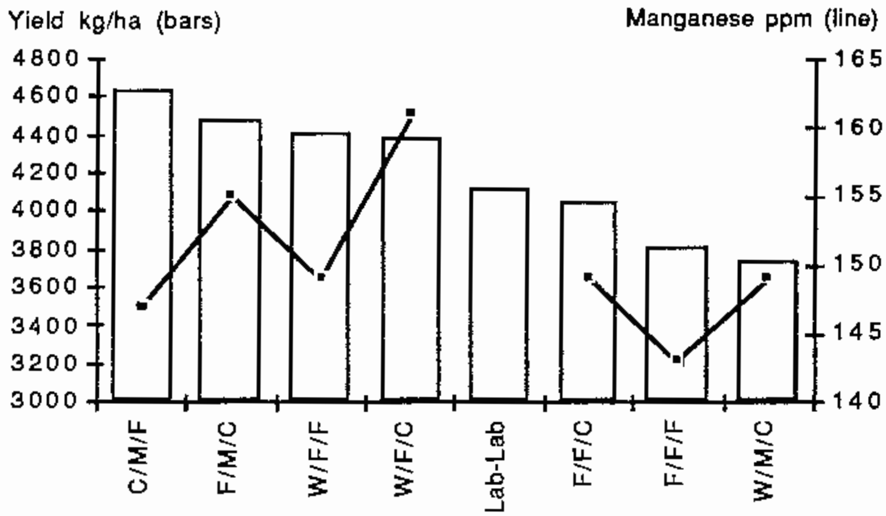


Figure 11.

Seed cotton yield and leaf manganese content of cotton following a range of crop rotations. C=chickpea; F=fallow; W=wheat; M=maize.

These results show clearly that crop rotation can have a very significant effect on the micro nutrition (mycorrhiza) of a subsequent cotton crop.

OVERALL SYNTHESIS OF GALATHERA SYNDROME

1. The finding (mostly by others such as Nehl and Allen) that mycorrhiza are involved in the Galathera syndrome has been a major finding. The production improvement obtained by Auscott in the past two seasons can be at least partly attributed to rotation and tillage being considerate of soil biology.

2. In general, responses to fertilizer treatments have been disappointing. Given that the Galathera syndrome is associated with a soil biology problem, then it is not surprising that fertilizer will not be a complete cure. Some inconsistent responses have been obtained to both soil and foliar zinc.

- ***Despite the inconsistency of these results, the fertilizer recommendation for this soil should be to apply soil Zn incorporated at 20 kg Zn/ha in the first season and to also apply foliar Zn at 200 g Zn/ha at squaring each subsequent year.***

3. Plant tissue analyses can assist with a diagnosis of the Galathera problem. High levels of manganese are consistently associated with poor mycorrhizal infection.

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2. Waterlogging induced iron chlorosis

This experiment was located on a field in 1991/92 which regularly shows symptoms of waterlogging induced iron chlorosis. These symptoms are quite distinct, with chlorosis in leaves which are expanding during waterlogging. Thus after the soil dries, and new leaf production continues, there is a zone on the plant where the leaves are yellow - higher and lower leaves are green.

Past observations have shown that the symptoms are well related to a high P/Fe ratio in leaf tissue. Leaf tissue analyses for the two occasions where symptoms were recorded, are as follows:

Table 29. Tissue analysis at sites where iron chlorosis has been observed.

Site	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
Oakville	4.4	.63	2.6	2.4	.48	.50	69	97	66	12
Colly	-	.30	1.7	2.1	.34	.46	32	71	19	8

At both sites, the levels were within acceptable critical limits. At Oakville the deficiency could be associated with a high P/Fe ratio (91; when 49 is desirable). At Colly the absolute iron level was fairly low, but again there was a high P/Fe ratio (94); there was also a low Fe/Mn ratio (.45; when .9 is desirable).

In the 1991/92 season the experiment was aimed to see whether P could be used to induce the problem and to see whether N could help ameliorate the waterlogged condition. A factorial experiment was set up where all combinations of plus and minus N, P and Fe were added to the soil before sowing.

Table 30. Overall mean tissue levels in December 1991 at an iron chlorosis site.

P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	P/Fe
.29	1.53	2.31	.60	.59	74	80	17	8	40

Based on previous observations, the P/Fe ratio was good - the absolute level of Zn was marginal.

Significant results

1. Leaf tissue P levels were increased and Fe levels decreased by P

P applied (kg/ha)	P (%)	Fe (ppm)
0	0.27	69
50	0.32	79
sed	0.013	3.9

2. Leaf tissue Zn levels were increased by Fe and leaf tissue P/Fe ratios were decreased by Fe

Fe applied (kg/ha)	Zn (ppm)	P/Fe
0	16.1	44
5	17.8	36
sed	0.66	2.5

3. Lint yields were not significantly affected by N, P or Fe treatments. The yield level in the field was over 8 bales/ha, indicating the crop was not affected by a chronic nutrient problem. The absolute yield response to Fe was as follows:

Fe applied (kg/ha)	Yield (kg/ha)
0	1878
5	1937
sed	44 (ns)

4. Foliar treatments were applied in the same field by Stuart Murray and Bob Eveleigh. Results from their experiments are as follows:

Small scale	
Treatment	Yield (kg lint/ha)
Control	1826
2*270gFe/ha	1987
3*270 gFe/ha	1781
2*270 gFe+2.5 kg N/ha	1907
3*270 gFe+2.5 kg N/ha	2083
2*140 gFe+140 gN + 140 g Zn/ha	1969
3*140 gFe+140 gN + 140 g Zn/ha	1976
sed	95

Large scale	
Treatment	Yield (kg lint/ha)
Control	1806
Fe	1897
Fe + N	2069
Fe + N + Zn	2240
sed	150(ns)

The small scale experiment indicated a significant response to multiple applications of iron and nitrogen, with a trend toward responses to zinc as well. None of the differences in the large scale experiment were significant, but there were trends towards responses to all nutrients.

It is clear that the symptoms this season were not due to iron chlorosis alone. That result emphasises the need to supplement visual diagnoses with tissue analyses.

C. COTTON LEAF NUTRIENT LEVELS

In 1989/90, a survey was begun to establish desirable levels of elements in cotton leaves. That sampling continued for three seasons. Listed below are levels found in a survey of 67 healthy cotton crops at the early flowering stage. The uppermost fully expanded leaf was sampled at each location. These leaf sampled were washed in distilled water before drying and chemical analysis. The levels are **not** intended to indicate the optimum levels for each element. They are the levels occuring in good cotton. Experiments to determine precise optimum levels of all nutrients are difficult to establish, because our soils are generally high in most elements.

Element	Units	Level
N	%	**4.29**
P	%	**0.36**
K	%	**1.36**
Ca	%	3.08
Mg	%	0.59
S	%	0.83
Mn	**ppm**	**80**
Fe	**ppm**	**76**
Zn	**ppm**	**25**
Cu	**ppm**	**8.9**
Na	%	0.10
Cl	%	1.18
Al	ppm	50
Si	%	.02

The variation of these data is also important: Phosphorus was the least variable data in the survey, with a coefficient of variation of 17% (standard deviation 0.06 ppm). Other elements with lower variation were zinc and copper. The frequency distribution of the zinc data is shown in Figure 12. Sulphur had the most variable data; the coefficient of variation was 51% (standard deviation 0.4%). Manganese and iron were also variable.

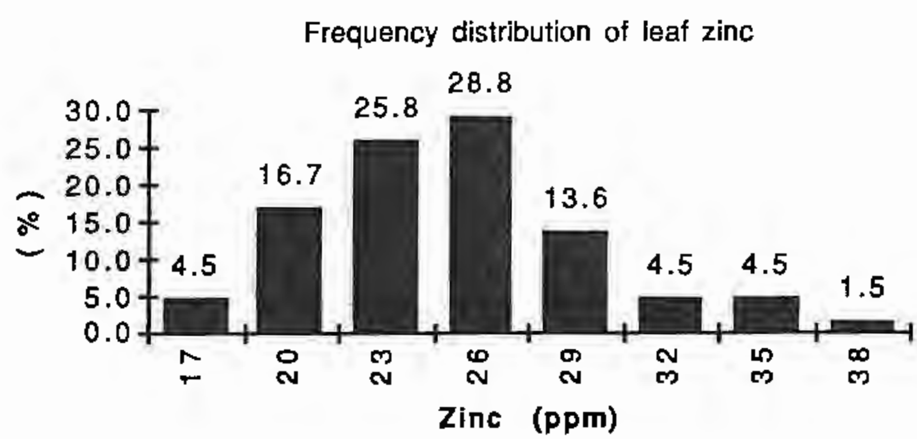

Figure 12.

The variation in zinc in cotton leaves from the survey

These data can now be used to assist with diagnosis of leaf tissue.

In association with the CSIRO group at Narrabri producing packages, a decision support package (nutriLOGIC ?) and a written manual (NUTRIpak ?) are planned. The proposed CRC has those items to be included in a sub-program led by Lance McKewen.

Those packages will utilise these survey data, ~~the~~ and results from specific experiments where deficiency is known.

Recommendations will be produced from:

Nitrogen experiments in past years at Narrabri and other sites (Greg Constable)

Potassium experiments from Emerald (Graham Harden)

Zinc and iron experiments from this report. Indicators of zinc deficiency are the absolute level of zinc (eg 12 ppm is accepted as critical) and the ratio between manganese and zinc (a ratio of 3 is ideal - note where Galathera sites have Mn/Zn ratios in excess of 5). Indicators of iron deficiency is the absolute level (eg 30 ppm is accepted as critical) and the ratio between phosphorus and iron (a ratio of 49 is ideal - note that waterlogging induced iron chlorosis produces P/Fe ratios of 90).